MEASUREMENT OF DIRECT CP VIOLATION BY THE NA48 EXPERIMENT AT CERN

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The NA48 experiment at CERN has performed a measurement of direct CP violation in the neutral kaon system, based on data collected in 1997 and 1998. The preliminary result for the parameter $\Re(\epsilon'/\epsilon)$ is $(14.0 \pm 4.3) \times 10^{-4}$.

1 Introduction

CP violation occurs in the Standard Model through the imaginary phase in the CKM mixing matrix. An alternative mechanism, proposed shortly after the discovery of the effect[1], is a superweak interaction[2]. The latter can be ruled out by experimental observation of direct CP violation, parametrized by ε'. Theoretical calculations of ε' within the Standard Model are hard, but most predictions give $\varepsilon'/\varepsilon \sim \mathcal{O}(10^{-6})$ [3].

The previous generation of experiments to measure direct CP violation (NA31[4] at CERN and E731[5] at Fermilab) gave inconclusive results. New experiments were setup to clarify the situation. In 1999 both new experiments presented results based on the first set of their statistics: Re$(\varepsilon'/\varepsilon)$=$(28.0 \pm 4.1)\times 10^{-4}$ (KTeV, FNAL)[6] and Re$(\varepsilon'/\varepsilon)$=$(18.5\pm 7.3)\times 10^{-4}$ (NA48, CERN)[7]. The existence of direct CP violation is thus confirmed. The final results of these two experiments, with substantially smaller uncertainties, are expected to conclude on the size of the direct CP violation effect.

The experimental determination of Re$(\varepsilon'/\varepsilon)$ is based on the fact that the two CP violating neutral kaon decay amplitudes into two pions

$$\eta_{+-} \equiv \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} \simeq \varepsilon + \varepsilon' \qquad \eta_{00} \equiv \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} \simeq \varepsilon - 2\varepsilon' \tag{1}$$

contain different admixture of the two CP violating processes in charged and in neutral mode. Therefore a double ratio

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} \tag{2}$$

is an observable sensitive to ε'/ε via Re$(\varepsilon'/\varepsilon) \simeq \frac{1}{6}(1-R)$.

This paper describes the preliminary result from the analysis of data taken by NA48 in 1998.

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2 NA48 method

To measure $\mathrm{Re}(\varepsilon'/\varepsilon)$ to an accuracy of $\mathcal{O}(10^{-4})$, high statistics and good controls of systematic biases are required. NA48 uses nearly collinear simultaneous K_S and K_L beams for maximum benefit from cancellations in the double ratio. By weighting K_L decays to the K_S lifetime distribution, performing the analysis in bins of kaon energy and collecting all four modes simultaneously, effects due to detection efficiencies and accidental activity are minimised. Low backgrounds are obtained by using high resolution detectors.

3 Experimental setup

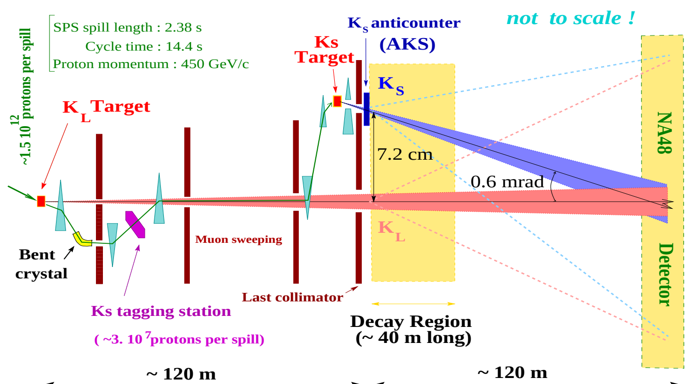


Figure 1. The layout of the NA48 experiment (side view).

The NA48 beams and detector are described in detail in [8]. A schematic is shown in figure 1, and the key feaures are listed below.

- A primary beam of 450 GeV protons ($\sim 1.4 \times 10^{12}$ ppp) is delivered by the SPS accelerator to the K_L target. A bent crystal deflects the required small fraction ($\sim \mathcal{O}(10^{-5})$) of the non-interacting protons through a system of tagging counters[10] and onto the K_S target.

- The $\pi^0\pi^0$ decays are reconstructed using a liquid krypton electromagnetic calorimeter ($\frac{\sigma_E}{E} = [0.5 \oplus \frac{3.2}{\sqrt{E/\mathrm{GeV}}} \oplus \frac{10.}{E/\mathrm{GeV}}]\%$). The neutral trigger[11] uses calorimeter information and a look-up table to make a fast decision. The inefficiency for $2\pi^0$ decays is $\sim$0.1 %.

- A magnetic spectrometer detects $\pi^+\pi^-$ decays. The momentum resolution is $\frac{\sigma_P}{P} = [0.5 \oplus 0.009P(\mathrm{GeV}/c)]\%$. The charged trigger consists of a fast pretrigger and a processor farm[12] which computes the decay vertex position and invariant mass from the drift chamber signals. This trigger has an inefficiency of $\sim$2.5%, and dead time of $<$5 %.

4 Data analysis

4.1 Event selection and backgrounds

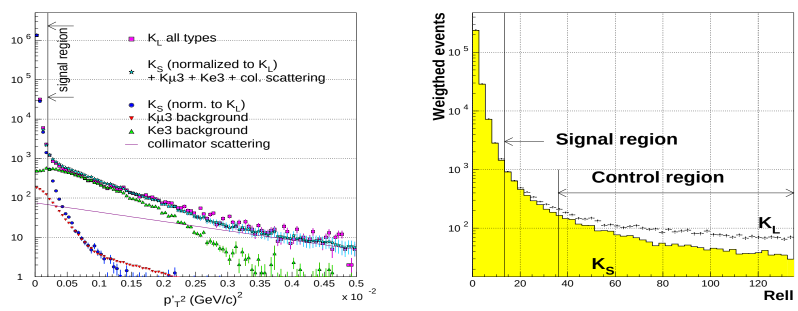
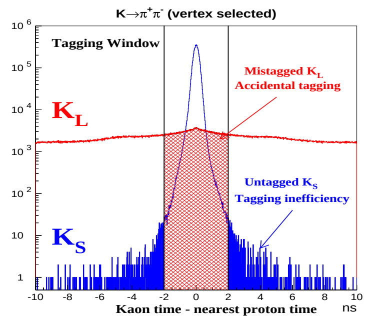


Figure 2. (left) Distribution of charged signal and background components in the rescaled transverse momentum squared (${p'_T}^2$); (right) Distribution of neutral signal and background components in the χ^2-like variable $R_{ellipse}$.

- All four modes are counted in the same kaon energy interval (70 to 170 GeV), and decay volume (0 to 3.5 K_S lifetimes). The beginning of the K_S decay volume is determined by an anti-counter placed in the K_S beam.
- Dead time in the trigger or read out is applied to all four modes.
- For charged events, the momentum asymmetry rejects background from decays of Λ particles. Cuts on E/p and associated muon counter hits reject the semi-leptonic backgrounds. A signal region in invariant mass and rescaled transverse momentum squared is used. The background is estimated using cleanly identified background decays (figure 2).
- For neutral events no additional clusters are allowed. The four clusters must have a low χ^2 for a $K^0 \rightarrow 2\ \pi^0 \rightarrow 4\ \gamma$ hypothesis. The background is measured from the tail of this distribution (figure 2).

4.2 K_S tagging



$$\alpha_{SL}^{+-} = (1.97 \pm 0.05) \times 10^{-4}$$
$$\alpha_{LS}^{+-} = (11.05 \pm 0.01)\%$$
$$|\Delta\alpha_{SL}| < 0.5 \times 10^{-4}$$
$$\Delta\alpha_{LS} = (0.3 \pm 4.2) \times 10^{-4}$$

Figure 3. The time difference between $K \to \pi^+\pi^-$ candidates and the nearest proton time detected by the tagging counter. The K_L and K_S contributions are identified by vertical vertex separation. On the right the calculated tagging quantities are given.

Decays from the K_S beam are identified by virtue of their having a coincidence between the event time and the nearest proton time as shown in figure 3. There are two forms of mistagging: *tagging inefficiency* (α_{SL}) - at least one of the two times was mismeasured, and *accidental tagging* (α_{LS}) - there was an accidental coincidences between a proton and a K_L decay. The double ratio is sensitive only to differences between the mistagging probabilities:

$$\Delta R_{SL} \simeq 6(\alpha_{SL}^{00} - \alpha_{SL}^{+-}) = 6\Delta\alpha_{SL} \qquad \Delta R_{LS} \simeq 2(\alpha_{LS}^{00} - \alpha_{LS}^{+-}) = 2\Delta\alpha_{LS} \quad (3)$$

$\Delta\alpha_{SL}$ is measured using $3\pi^0$ decays with one photon conversion, The value of $\Delta\alpha_{LS}$ is estimated using sidebands away from the coincidence peak.

4.3 Acceptance and proper time weighting

To avoid a large acceptance correction on the double ratio due to the difference between the two neutral kaon lifetimes, the K_L candidates are weighted with a factor to make the lifetime distributions the same. After weighting the acceptance correction reduces to a value of $\Delta\mathrm{R} = (+31 \pm 6_{MCstat} \pm 6_{syst}) \times 10^{-4}$, with an increase of statistical error of $\sim$35 %.

4.4 Other systematics

In order to avoid strong sensitivity to the distance scale uncertainty the beginning of the decay region is defined by an anti-counter, placed in the K_S beam.

In the neutral decay mode the distance scale is directly related to the energy scale. The total uncertainty on the double ratio from neutral reconstruction systematics is $< 10 \times 10^{-4}$.

Care has to be given to losses and gains in the event counts due to accidental activity. The correction on the double ratio due to different K_S/K_L illumination of the detector (calculated by overlaying data with events triggered proportionally to the beam intensity) is $(2 \pm 6) \times 10^{-4}$. Other effects (variation of the K_S/K_L intensity ratio, noise) are absorbed in a limit of $< 10 \times 10^{-4}$.

5 Result

Table 1 shows the statistics collected in 1998 run, next to a list of all corrections applied to the raw double ratio and of all systematic uncertainties.

Mode	Statistics/10^6
$K_S \to \pi^+\pi^-$	7.5
$K_L \to \pi^+\pi^-$	4.8
$K_S \to \pi^0\pi^0$	1.8
$K_L \to \pi^0\pi^0$	1.1

$\Rightarrow$

Statistical error on R : 17.3×10^{-4}

Source	ΔR/10^{-4}
Charged trigger	-1$\pm$ 11
Accidental tagging	+1$\pm$ 8
Tagging efficiency	0$\pm$ 3
Neutral rec. syst.	0$\pm$ 10
Charged vertex	+2$\pm$ 2
Acceptance	+31$\pm$ 9
Neutral BKG	-7$\pm$ 2
Charged BKG	+19$\pm$ 3
Beam scattering	-10$\pm$ 3
Accid. activity	+2$\pm$ 12
Total	+37$\pm$ 24

Table 1. The statistical and systematic errors in the double ratio. In order to obtain the effect on $\mathrm{Re}(\varepsilon'/\varepsilon)$ the numbers must be scaled down by factor 6.

The stability of the corrected double ratio (figure 4) has been extensively checked. The preliminary result obtained from the data collected in the year 1998 is

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 2.9_{stat} \pm 4.0_{syst}) \times 10^{-4}. \quad (4)$$

The combined 1997 and 1998 result is

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (14.0 \pm 4.3) \times 10^{-4}. \quad (5)$$

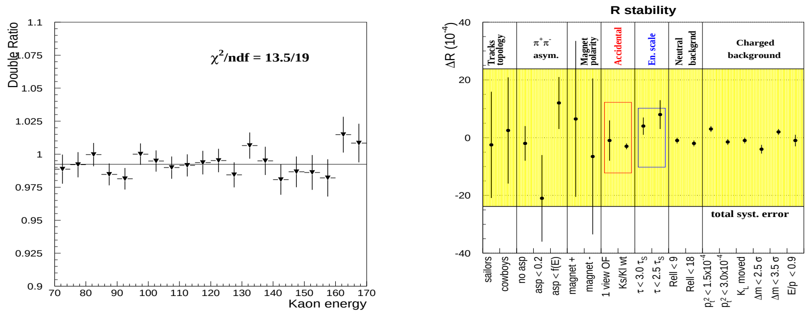


Figure 4. The stability of the double ratio with kaon energy (left) and other checks (right).

6 Conclusions and outlook

The result presented in this paper confirms the existence of the direct CP violation. Further analysis on systematic studies and the data collected in the 1999 run should lead to a total uncertainty on $\mathrm{Re}(\varepsilon'/\varepsilon)$ of $\lesssim 3 \times 10^{-4}$.

Taking into account the three most precise published results[4,5,6] and the combined NA48 result the world average is $\mathrm{Re}(\varepsilon'/\varepsilon) = (19.3 \pm 2.4) \times 10^{-4}$. However the $\chi^2 = 10.5/3$ indicates poor consistency among the values. New results with better accuracy from both KTeV and NA48 as well as first results from KLOE[13] at DAϕNE should help to clarify this situation.

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